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**FAILURE ANALYSIS OF 120-MM
MORTAR BUSHINGS AND FIRING PINS**

KATHRYN E. NOLL



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13. ABSTRACT (Maximum 200 words) A failure analysis was performed on several 120-mm mortar bushings and firing pins. The analysis entailed examining (1) the failed firing pins and bushings for conformance to drawing requirements, and (2) the material differences between the U.S.-made and the Israeli-made components. The evaluation included visual examination, metallographic examination, microhardness determination, chemical composition determination, and scanning electron microscopy. The firing pins essentially met the required material specifications. However, it could not be determined whether the bushings met the requirements due to the vagueness of the drawing specifications. There were no observable material differences between the U.S.-made and the Israeli-made firing pins. The U.S.-made bushings did have a larger grain size, and the inner diameter of the bushing showed a slight surface degradation and rougher topography than the Israeli-made bushing. This difference in the inner diameter was due to the machining process, wire electrical discharge machining, that was used to produce the U.S.-made bushings.				
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INTRODUCTION

A failure analysis was performed on several 120-mm mortar bushings and firing pins. The bushings were part of the firing bushing assembly (Drawing 12576982) and reportedly were made from tungsten carbide. The firing pins reportedly were made from 17-4 PH stainless steel. A total of six firing pins and four bushings were examined. Three of the pins had not been subjected to firing, but were included for comparative purposes. Table 1 details the components examined.

Table 1. Components Examined

Component	Shown In	Assembled With	Firing Rounds	Manufacturer
Pin 1	Figure 1	Bushing 1	548	U.S.
Pin 2	Figure 2	Bushing 1	8*	U.S.
Pin 3	Figure 4	Bushing 2	613	U.S.
Pin 4	Figure 6		Unfired	U.S.
Pin 5 (Prototype Pin)	Figure 7		Unfired	Israel
Pin 6 (Production Pin)	Figure 8		Unfired	Israel
Bushing 1	Figure 3	Pins 1 and 2	556	U.S.
Bushing 2	Figure 5	Pin 3	613	U.S.
Bushing 3	Figure 9		Proof-Fired	U.S.
Bushing 4			Proof-Fired	Israel

* Bushing 1 was not inspected for damage prior to installation of the second firing pin (Pin 2).

The hole in the U.S.-made bushings (arrows, Figure 9) was cut using wire electrical discharge machining (EDM). The Israeli bushing was cut with a conventional machining operation.

The objectives of the analysis were (1) to determine whether the failed firing pins and bushings met the required materials specifications per Drawings 12576987 and 12577390, respectively, and (2) to determine if there were any material differences between the U.S.-made and the Israeli-made firing pins and bushings.

PROCEDURE

The evaluation consisted of the following analyses:

- Visual examination
- Metallographic examination
- Microhardness testing
- Chemical analysis
- Scanning electron microscopy (SEM)

RESULTS

Visual Examination

A visual examination was performed on the as-received firing pins and bushings in order to identify any significant features. Pins 1 and 2 displayed extensive damage toward the tip of the pin. Bushing 1 shown in the center of the bushing assembly in Figure 3 was also visibly damaged. The discoloration observed on the face of the bushing assembly is not considered unusual for components that have been subjected to firing tests. Pin 3 sustained minor damage (arrows, Figure 4), with the bushing assembly (Figure 5) displaying no visible damage to Bushing 2. The unfired pins (Pins 4, 5, and 6) were supplied for comparison with the fired pins. From the visual examination, there were no observable differences between the unfired U.S.-made and unfired Israeli-made firing pins.

The bushing assemblies were then sectioned (Figure 10) and the bushings (arrows, Figure 10) were removed in order to further characterize the component. Overall photographs of the four bushings are shown in Figures 11 through 14. Bushing 1 sustained the more severe damage seen in Figure 11, with the inner diameter being affected down the entire length of the bushing. Bushing 2 experienced slight damage to the inner diameter of the bushing (Figure 12). Bushings 3 and 4 were supplied for comparison with the damaged bushings. From the visual examination, there were no observable differences between the proof-fired, U.S.-made and proof-fired, Israeli-made bushings (Figures 13 and 14, respectively).

The three damaged firing pins and the four bushings were further characterized using the scanning electron microscope. Details of this examination are described below.

Metallographic Examination

Metallographic samples were prepared in the longitudinal direction for the firing pins and bushings. The samples were examined in both the as-polished and etched conditions.

All six firing pins displayed similar microstructures in the bulk of the material. Figures 15 and 16 show representative photomicrographs of the firing pins in the as-polished and etched conditions, respectively. The microstructure shown in Figure 16 is representative of a properly solution heat treated and aged 17-4 PH stainless steel alloy.

There were several areas, however, that did not exhibit this type of microstructure. The three fired pins displayed some microstructural variation near the damaged areas. Figures 17 and 18 show an as-polished and etched view, respectively, near the tip of Pin 1. The region displayed a much finer-grained microstructure than the rest of the material examined in Pin 1 (see Figure 16). Similar areas were also observed near the tip of Pin 2 and Pin 3 (Figures 19 through 22). The area shown in Figure 21b corresponds to the damaged region observed during the visual examination of Pin 3. This altered microstructure indicates that the three pins may have experienced some localized heating near the tip of the pins. Hardness measurements were taken in these areas and are described later in this report.

A representative photomicrograph of an as-polished bushing is shown in Figure 23. From the as-polished samples, all four bushings appeared to be similar. The bushings were then etched in Murakami's reagent to bring out the various constituents in the microstructure. Figures 24 through 27 show the microstructure of Bushings 1 through 4, respectively. Tungsten carbide particles in the photomicrographs are seen as light grey, angular particles. The grain size of a cemented carbide is determined by the size of the particles in the material. As can be clearly observed, the three U.S.-made bushings (Figures 24 through 26) show a larger grain size than the Israeli-made bushing (Figure 27). According to Drawing 12577390, the tungsten carbide bushings should have a grain size of 4 μm . Unfortunately, the drawing requirement does not specify whether this is an average grain size or a maximum allowed grain size. Therefore, grain size measurements were taken of both the average grain size and the largest grain size with results shown below in Table 2.

Table 2. Grain Size Measurements

Bushing No.	Average Grain Size (μm)	Largest Grain Size (μm)
1	2.4	8.5
2	2.5	12.5
3	2.6	12.5
4	1.9	5.5

For both measuring methods, the grain size of Bushing 4 was finer than the grain size of Bushings 1 through 3. Based on the drawing specification, it is not clear whether any of the bushings met the grain size requirements.

Microhardness Testing

Vickers microhardness measurements were taken of the firing pins and bushings and converted to the appropriate Rockwell hardness scales. Drawing 12576987 required that the firing pin material be hardened to Rockwell C 38 to 43, and Drawing 12577390 required that the tungsten carbide bushings have a hardness of Rockwell A 88.5. Firing pin measurements were taken on the unaffected regions of Pins 1 through 3. The results shown below in Table 3 are an average of the measurements taken.

Table 3. Rockwell Hardness Values of Pins and Bushings

Pin No.	HRC	Bushing No.	HRA
1	39.5	1	86.7
2	40.0	2	87.3
3	38.0	3	88.0
4	39.7	4	88.3
5	42.1		
6	38.8		

The hardness values of all the firing pins were within the required hardness range. The drawing requirement for the tungsten carbide bushing was again obscure. It is unclear whether the requirement is a minimum, maximum, or average value. However, the hardness values of the bushings were quite consistent.

The three damaged pins exhibited a variation in hardness along the length of the pins with the tip being softer (~33.0 HRC) than the remaining material. Hardness measurements were taken in the finer grained microstructure documented above. An average of the measurements was taken and the results are shown in Table 4.

Table 4. Average HRC Measurements

Area	HRC
Figure 18 (Pin 1)	33.5
Figure 20 (Pin 2)	33.0
Figure 22 (Pin 3)	32.0

These hardness values further suggest that the damaged pins experienced some localized overheating.

Chemical Analysis

Chemical analyses were performed on the six firing pins. According to Drawing 12576987, the required chemical composition for the firing pins is steel 17-4 PH per Aerospace Material Specification 5643. The results, shown below in Table 5, are given in weight percent.

Table 5. Chemical Composition of Firing Pins
(Weight Percent)

Element	Pin 1	Pin 2	Pin 3	Pin 4	Pin 5	Pin 6	Required
Chromium	17.41	16.64	16.51	15.62	14.33	17.46	15.00-17.50
Nickel	4.46	4.28	4.25	3.84	4.80	4.52	3.00-5.00
Copper	3.37	3.01	3.40	3.34	3.72	3.61	3.00-5.00
Carbon	0.046	0.043	0.041	0.046	0.050	0.045	0.07*
Manganese	0.864	0.848	0.780	0.778	0.342	0.360	1.00*
Silicon	0.489	0.466	0.450	0.461	0.495	0.540	1.00*
Phosphorus	0.022	0.018	0.018	0.017	0.017	0.030	0.040*
Sulfur	0.020	0.020	0.021	0.019	0.012	0.021	0.030*

* Maximum amount allowed.

All the firing pins examined essentially met the required chemical ranges. The chromium content in Pin 5 was slightly below the required range, but this deviation is not considered significant.

The drawing requirement for chemical composition of the tungsten carbide bushings was 90 percent tungsten carbide and 10 percent cobalt. Unfortunately, a quantitative chemical analysis was unable to be obtained. Energy dispersive spectroscopy was conducted on the bushings to give a qualitative analysis and all the bushings contained primarily tungsten, carbon, and cobalt.

Scanning Electron Microscopy

SEM was performed to further characterize the firing pins and tungsten carbide bushings. The three damaged pins are shown in Figures 28 through 30. A definitive fracture mode could not be determined for any of the firing pins. Pins 1 and 2 exhibited extensive damage with some regions displaying evidence of melting (Figures 28b and 29b). Pin 3 showed much less severe damage. Note the cracking network went beyond the damaged region (arrow, Figure 30b).

The four tungsten carbide bushings were examined and there were several noteworthy features observed. Bushing 1 (Figure 31) sustained considerable damage along the entire length of the inner diameter. Figure 32 shows the cracking network observed in the damaged regions. The cracking shown in Figure 33 was also seen in the other three bushings (Figures 34 through 36). Bushing 2 experienced slight damage to the inner diameter (arrows, Figure 34) and the cracking network was visible along the length of the bushing (see Figure 34b).

Bushings 3 and 4 were further examined to compare the U.S.- versus Israeli-made bushings. Figures 37 and 38 show a magnified view of the inner diameter surface. The two bushings displayed vastly different surfaces. Figure 37 shows a rougher surface topography than the Israeli-made bushing in Figure 38. The surface shown in Figure 37 was observed in all three, U.S.-made, wire EDM bushings. This type of surface was expected since the EDM process involves melting and/or vaporizing a thin layer of material during the machining. In the case of tungsten carbides, the electrical spark generated during the EDM process melts and rounds the normally sharp edges of the tungsten particles. This melting phenomenon is known as "remelt."

The EDM process also degrades the cobalt binder found in tungsten carbides. The cobalt binder holds the tungsten particles together in the material. The electrochemical reaction that degrades the binder causes a residue of loose tungsten particles to be left on the surface of the workpiece. Cross-sectional areas of the inner diameter of both Bushings 3 and 4 were examined are shown in Figures 39 and 40, respectively. There was a slight amount of degradation observed in the wire EDM surface of Bushing 3 (arrows, Figure 39).

SUMMARY

Based on our analysis, all six firing pins essentially met the required specifications for microstructure, hardness, and chemical composition. There were several areas observed in the three damaged pins that displayed a lower hardness and an altered microstructure. These areas were likely due to a localized overheating produced during firing. There were no observable material differences between the U.S.-made and the Israeli-made firing pins.

The four tungsten carbide bushings displayed microstructures and hardness values typical of a 90 percent tungsten carbide and 10 percent cobalt material. It could not be determined whether the bushings met the grain size and hardness requirements due to the vagueness of the drawing specifications. A qualitative chemical analysis was performed on the bushings verifying that the material was composed of tungsten, carbon, and cobalt.

There were several differences observed between the U.S.-made and Israeli-made bushings. The grain size was larger for the three U.S. bushings examined. The surface of the machined, inner diameter was also vastly different in the U.S.-made bushings. This appearance was due to the machining process used for cutting these bushings, namely wire EDM. Some slight surface degradation was also observed in the proof-fired, U.S. bushing (again caused by the wire EDM process). This degradation was not observed in the Israeli bushing.

CONCLUSION

The results of our investigation permit the following conclusions:

1. All six firing pins essentially met the required specifications for microstructure, hardness, and chemical composition.
2. All four tungsten carbide bushings displayed microstructures and hardness values typical of a 90 percent tungsten carbide and 10 percent cobalt material. A qualitative chemical analysis verified that the material was composed of tungsten, carbon, and cobalt.

3. There were no observable material differences between the U.S. and the Israeli firing pins.
4. The grain size was larger in the three U.S. bushings, than the Israeli bushing examined.
5. The surface of the machined, inner diameter of the three U.S. bushings showed a rougher surface topography than the inner diameter of the Israeli bushing.
6. Slight surface degradation was seen in the inner diameter of the proof-fired, U.S. bushing that was not observed in the Israeli bushing.

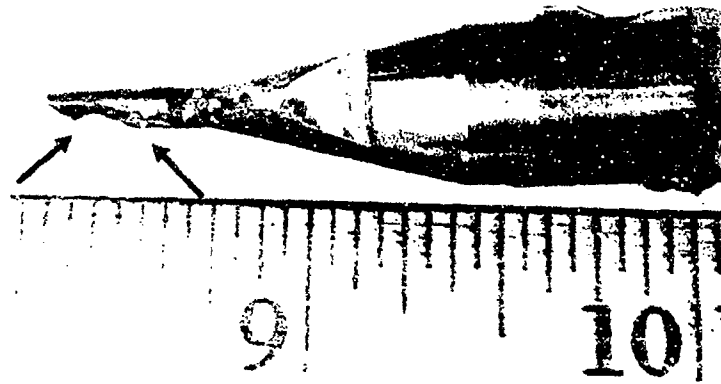


Figure 1. Photograph of Pin 1, as-received, with arrows pointing to the damaged area.

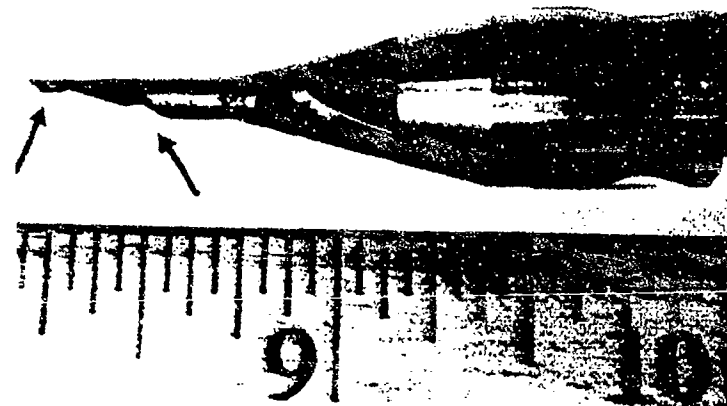


Figure 2. Photograph of Pin 2, as-received, with arrows pointing to the damaged area.

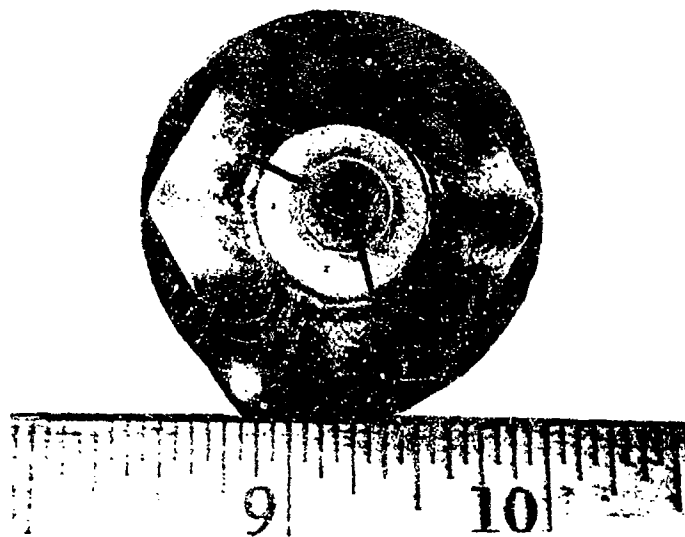


Figure 3. Photograph of bushing assembly, as-received, with arrows pointing to the damaged tungsten carbide of Bushing 1.

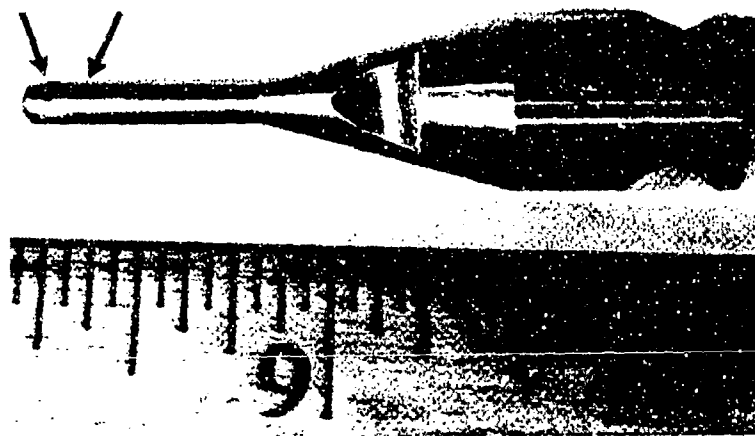


Figure 4. Photograph of Pin 3, as-received, with arrows pointing to the damaged area.

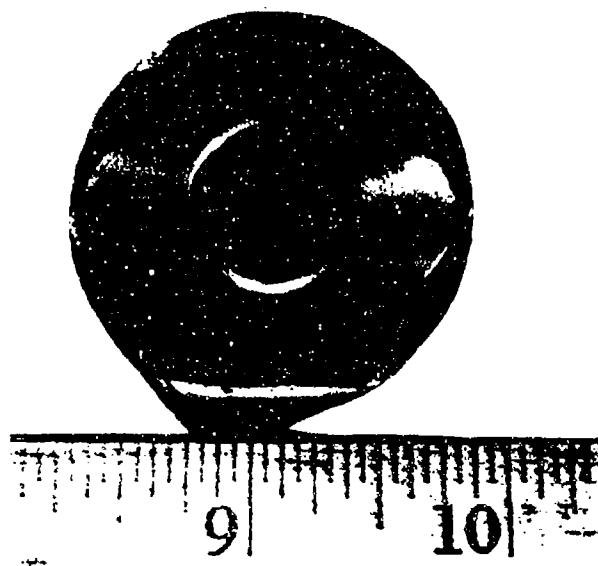


Figure 5. Photograph of bushing assembly, as-received, with Bushing 2 located at the center.

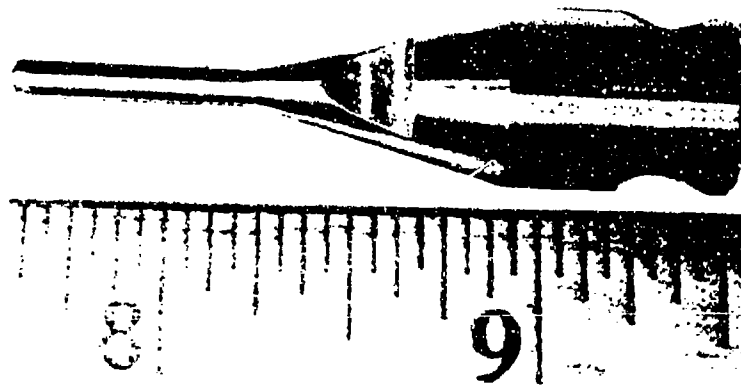


Figure 6. Photograph of Pin 4, as-received.

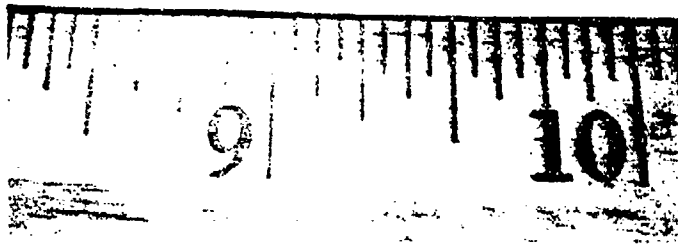


Figure 7. Photograph of Pin 5, as-received.

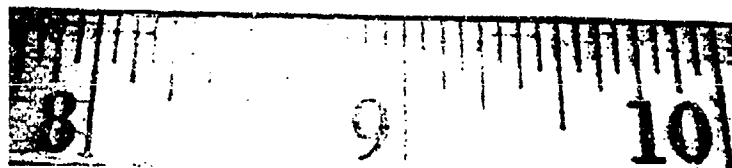


Figure 8. Photograph of Pin 6, as-received.

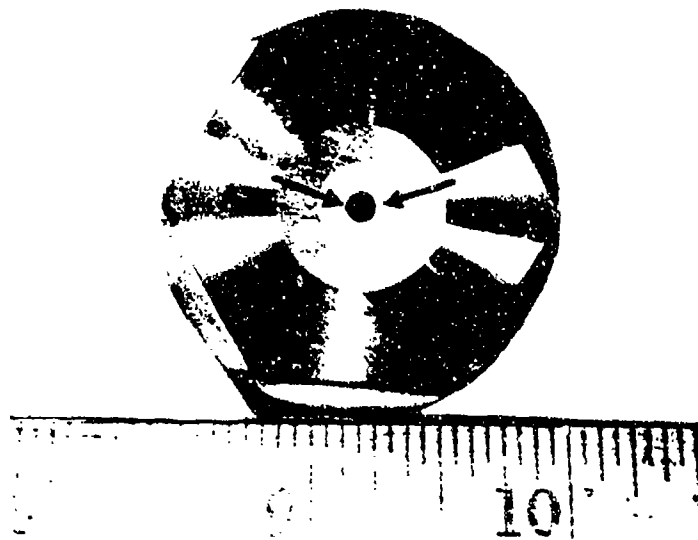


Figure 9. Photograph of bushing assembly, as-received, with Bushing 3 located at the center. Arrows point to the hole machined by wire EDM.

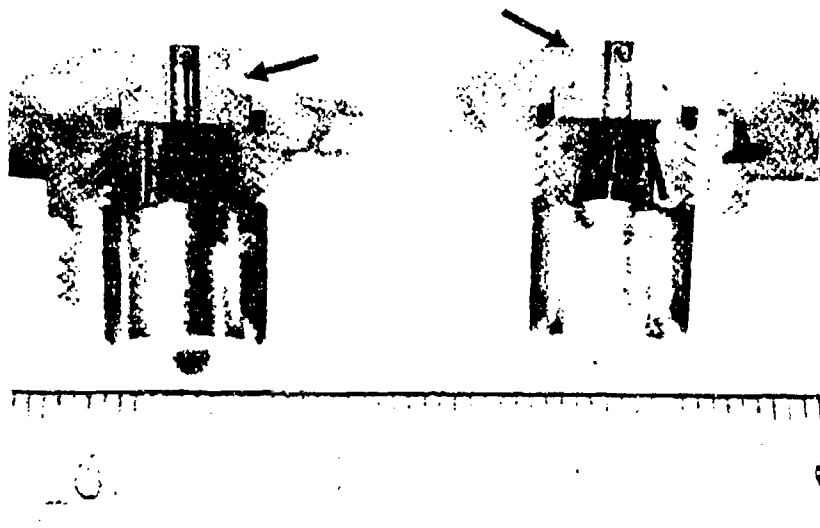


Figure 10. Photograph of a sectioned bushing assembly, with arrows pointing to the tungsten carbide bushing.



Figure 11. Longitudinal view of sectioned Bushing 1 displaying the amount of damage sustained during firing.



Figure 12. Longitudinal view of sectioned Bushing 2, with arrows pointing to the slight damage.



Figure 13. Longitudinal view of sectioned Bushing 3, with arrows pointing to the wire EDM inner diameter.



Figure 14. Longitudinal view of sectioned Bushing 4.

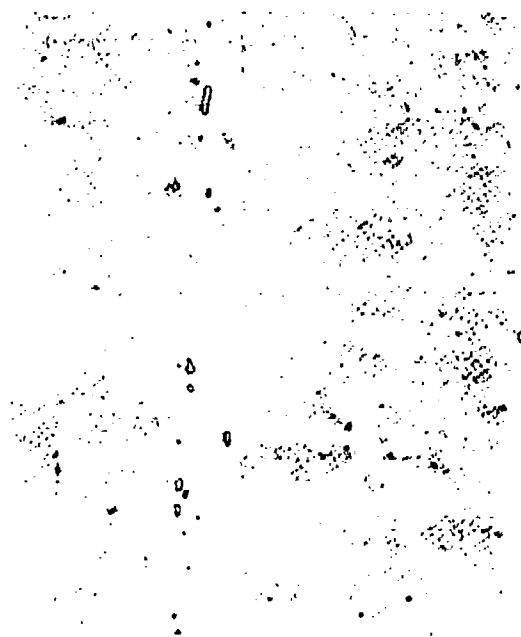
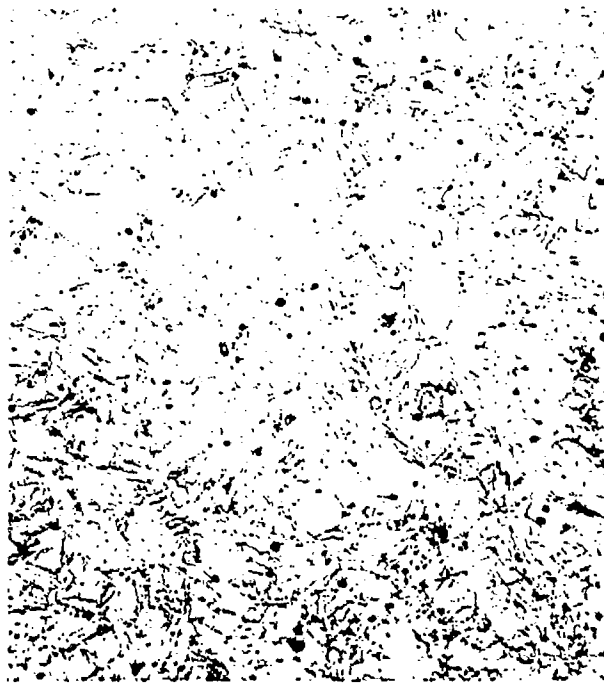


Figure 15. Representative photomicrograph of firing pin material, as-polished at 400X.



(a) 400X.



(b) 1000X.

Figure 10. Representative photomicrographs of 17-4 PH microstructure found in the bulk of firing pin material. Etched in equal amounts of HCl, HNO₃, and H₂O.



(a) 20X.



(b) 100X.

Figure 17. Photomicrographs showing as-polished view of Pin 1. Arrows point to location of microstructural variation.



(a) 400X.



(b) 1000X.

Figure 18. Photomicrographs of finer grained region (arrows) found in Pin 1. Shown in the etched condition.



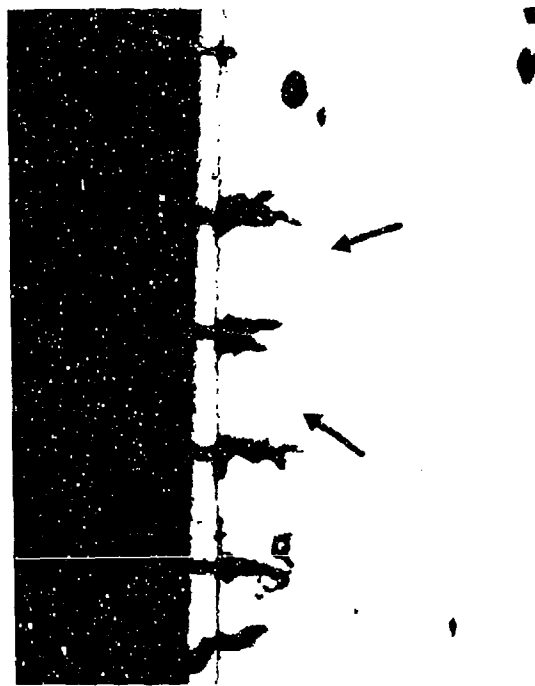
Figure 19. Photomicrograph showing as-polished view of Pin 2, at 400X.
Arrow points to location of finer grained microstructure.



Figure 20. Photomicrograph showing etched view of Pin 2, at 1000X.
Arrows point to location of finer grained microstructure.

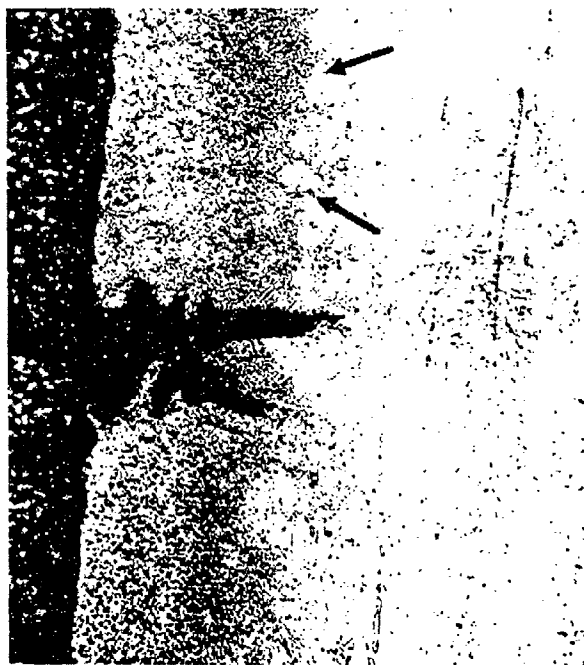


(a) 20X.

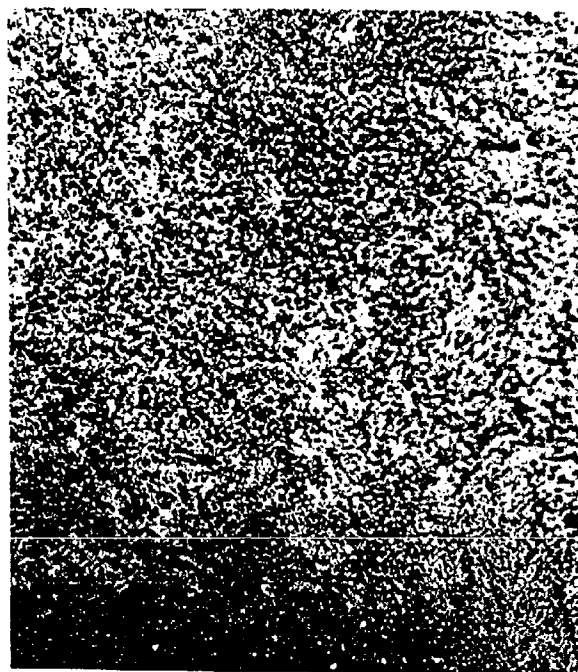


(b) 100X.

Figure 21. Photomicrographs showing as-polished view of Pin 3. Arrows point to location of microstructural variation.



(a) 400X.



(b). 1000X.

Figure 22. Photomicrographs of finer grained region (arrows) found in Pin 3. Shown in the etched condition.



Figure 23. Representative photomicrograph of tungsten carbide material, as-polished at 1500X.

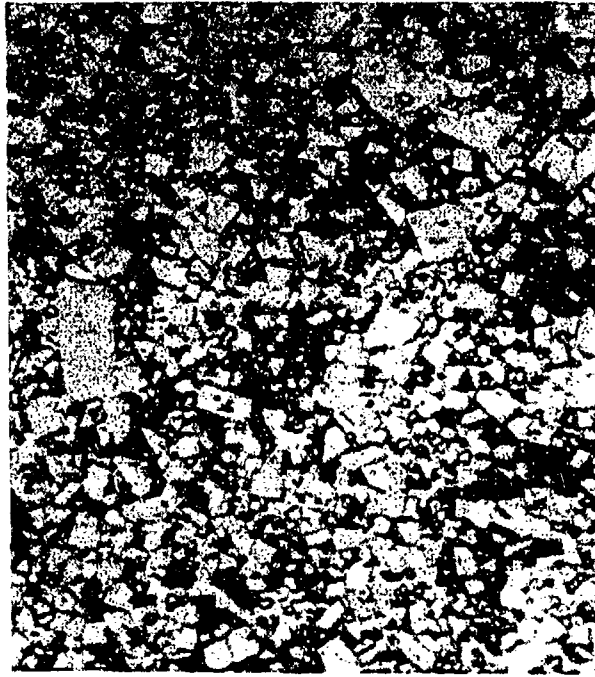


Figure 24. Photomicrograph of tungsten carbide microstructure found in Bushing 1, at 2000X. Etched in Murakami's reagent.

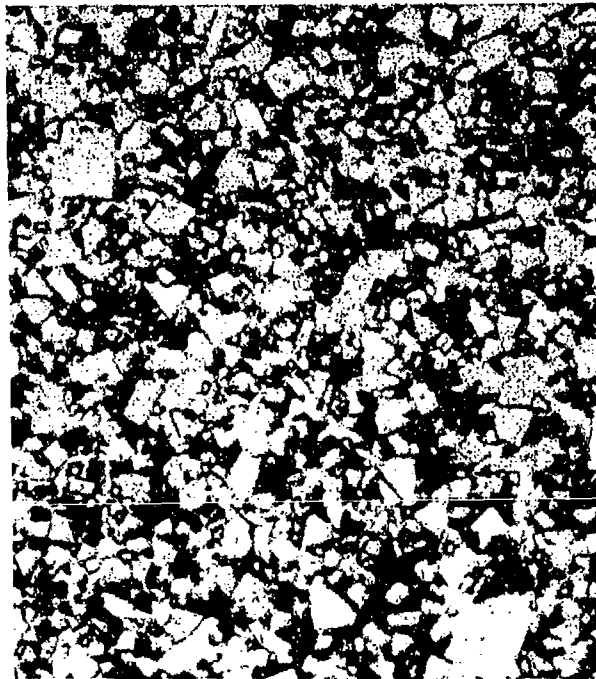


Figure 25. Photomicrograph of tungsten carbide microstructure found in Bushing 2, at 2000X. Etched in Murakami's reagent.



Figure 26. Photomicrograph of tungsten carbide microstructure found in Bushing 3, at 2000X. Etched in Murakami's reagent.

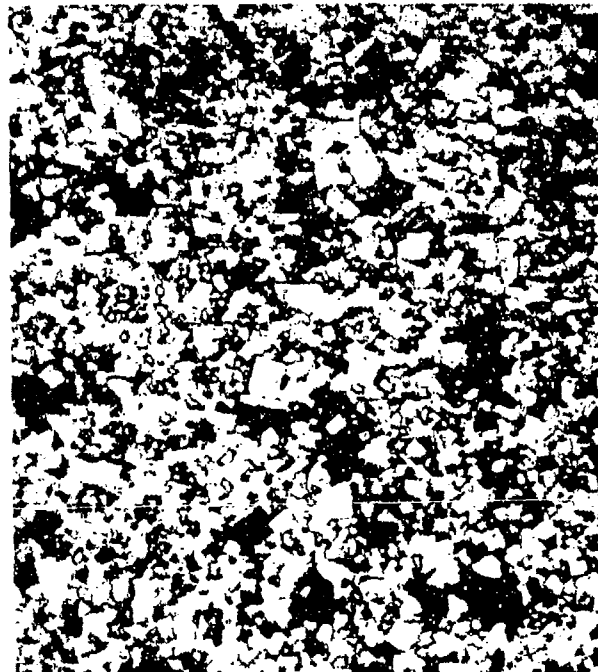


Figure 27. Photomicrograph of tungsten carbide microstructure found in Bushing 4, at 2000X. Etched in Murakami's reagent.



Figure 28a. SEM micrograph of Pin 1 showing the extent of damage, at 17X.

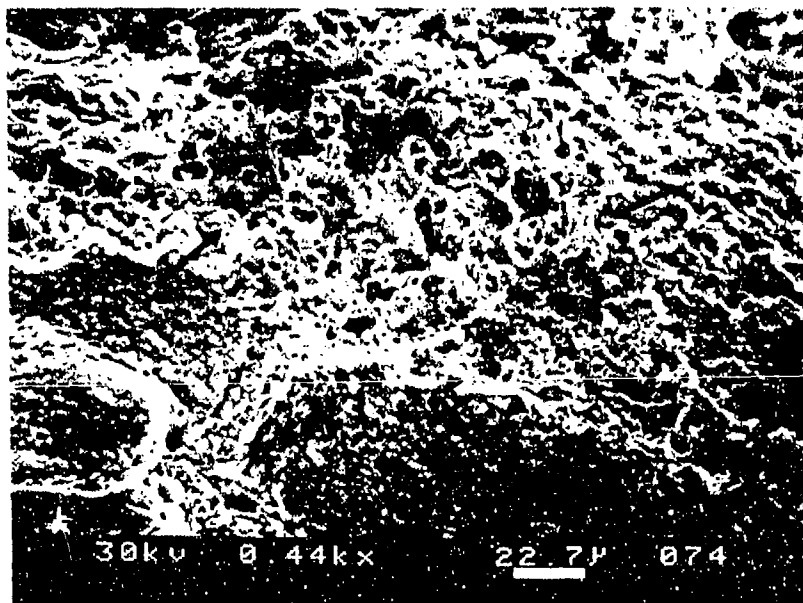


Figure 28b. Magnified view of Pin 1 showing area of melting, at 440X.
Region was located at the tip of Pin 1.



Figure 29a. SEM micrograph of Pin 2 showing the extent of damage, at 12X.

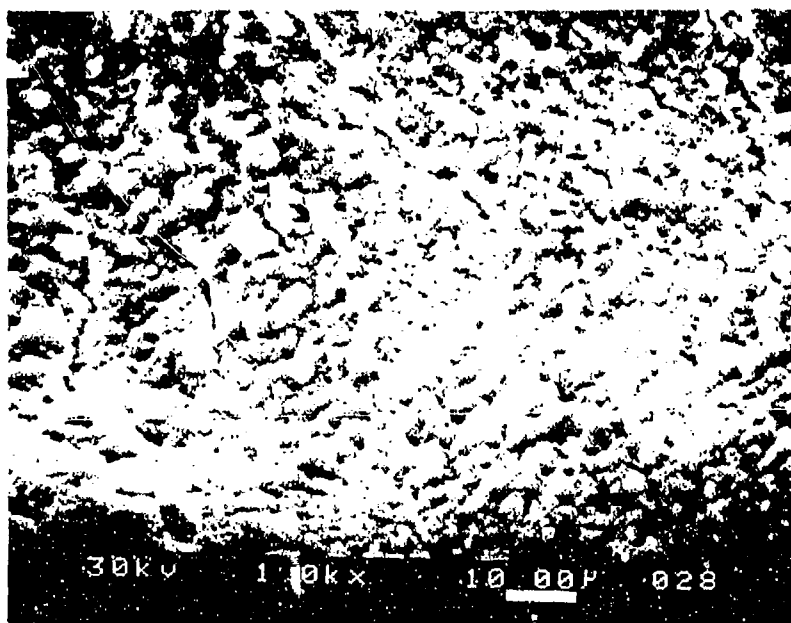


Figure 29b. Magnified view of Pin 2 showing area of melting, at 1000X. Region was located at the tip of Pin 2.

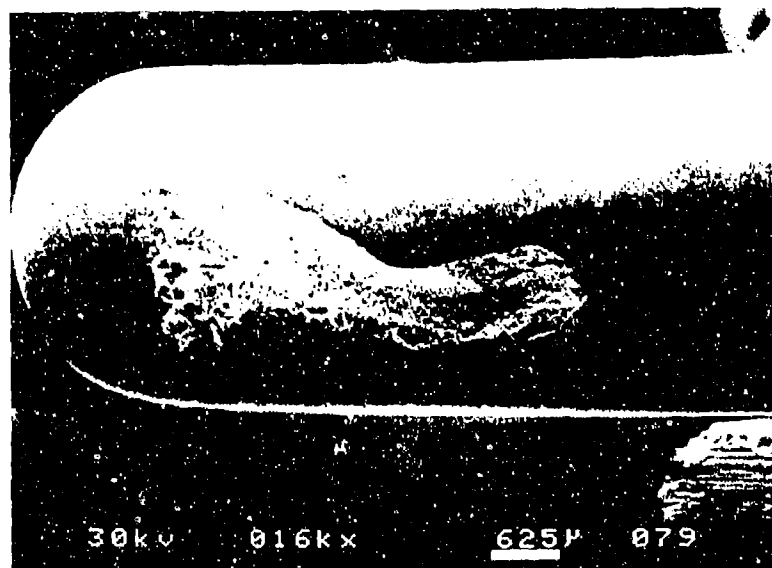


Figure 30a. SEM micrograph of Pin 3 showing the extent of damage, at 16X.

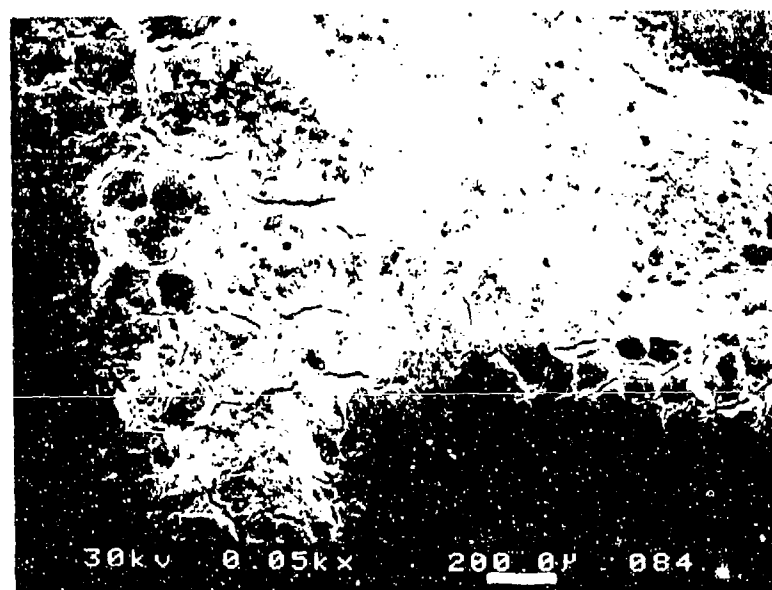


Figure 30b. Magnified view of damaged area in Pin 3, at 50X.
Arrow points to the cracking network.



(a)



(b)

Figure 31. SEM micrographs of sectioned tungsten carbide of Bushing 1, depicting the extent of damage to the inner diameter, at 11X.

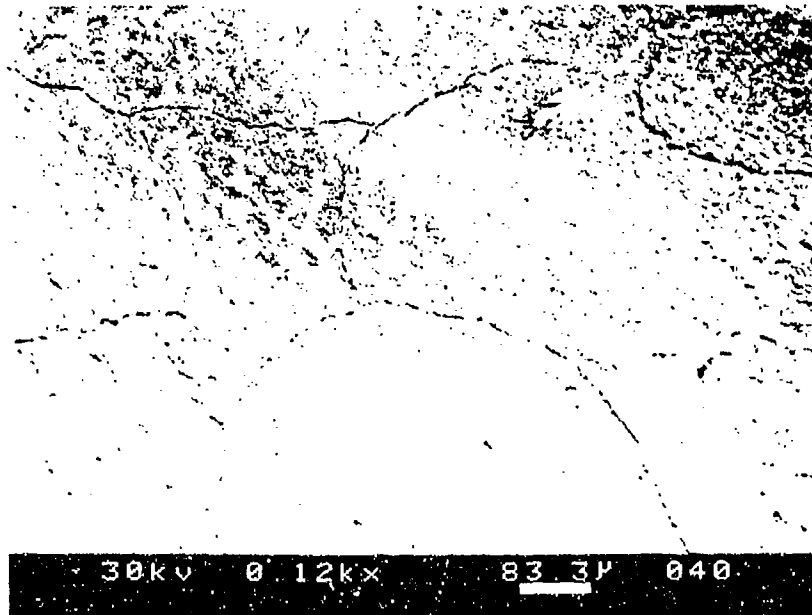


Figure 32. SEM micrograph displaying the cracking network observed in the damaged area of Bushing 1, at 120X.

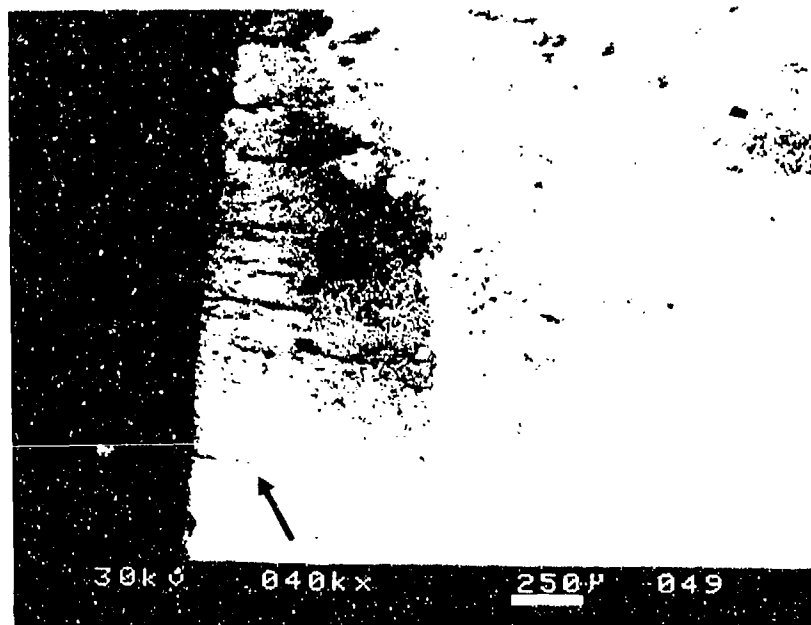
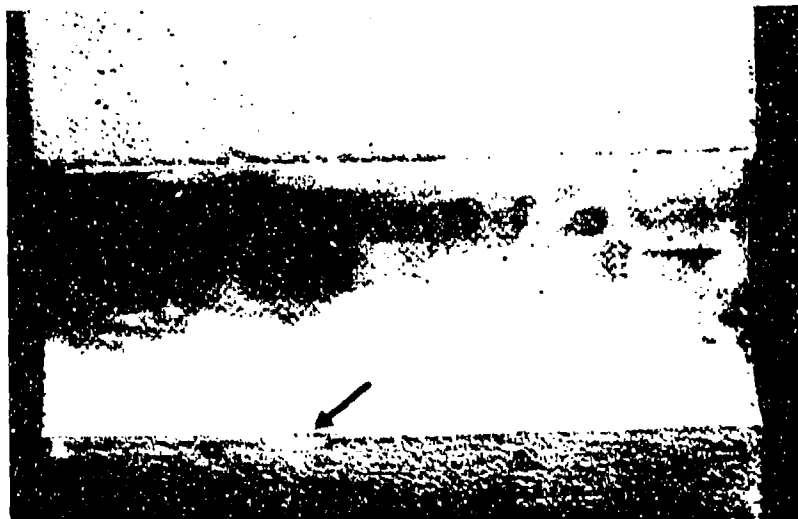


Figure 33. SEM micrograph displaying the cracking observed in the inner diameter of all four tungsten carbide bushings, at 40X.



(a)



(b)

Figure 34. SEM micrographs of sectioned tungsten carbide of Bushing 2, depicting the slight amount of damage to the inner diameter, at 11X.

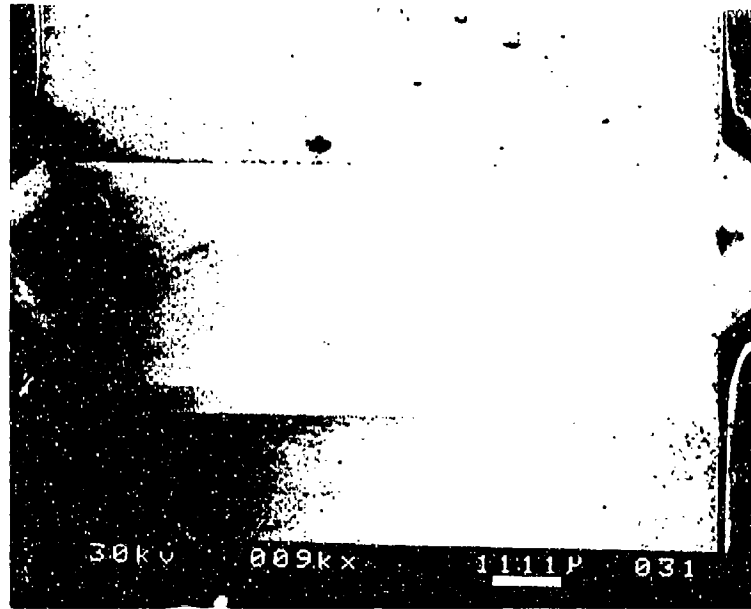


Figure 35. SEM micrograph of sectioned tungsten carbide of Bushing 3, at 9X.
The inner diameter was machined using wire EDM.

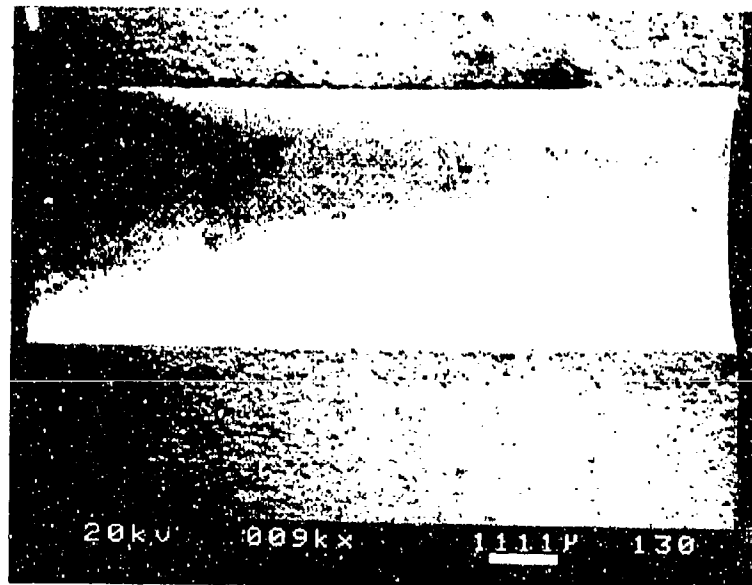


Figure 36. SEM micrograph of sectioned tungsten carbide of Bushing 4, at 9X.

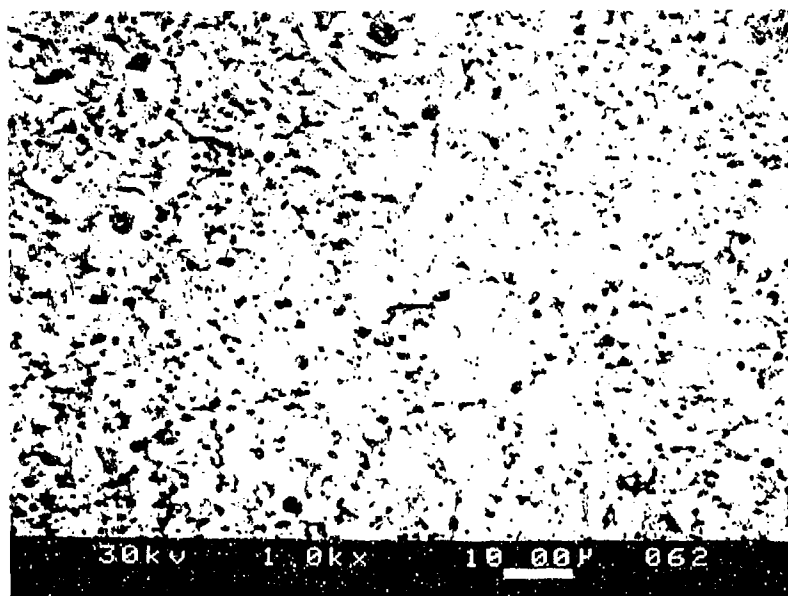


Figure 37. SEM micrograph showing magnified view of the wire EDM inner diameter surface of Bushing 3, at 1000X.

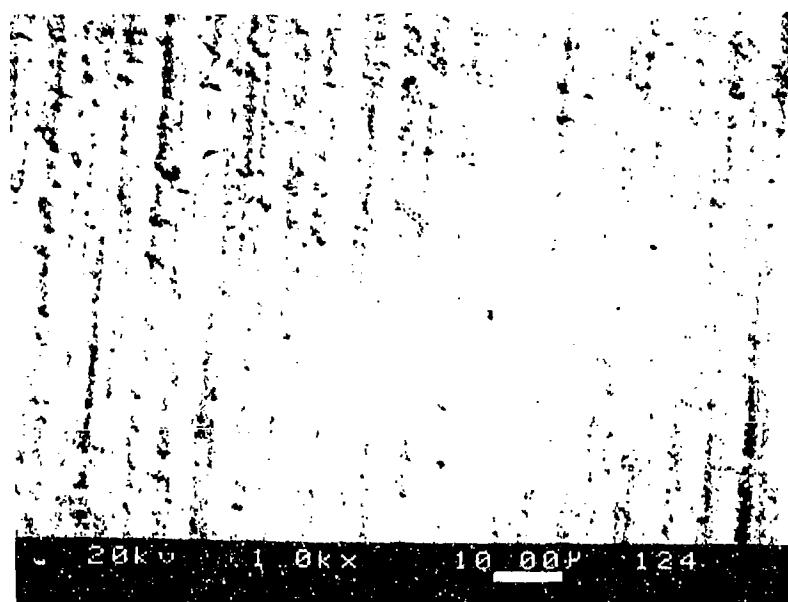


Figure 38. SEM micrograph showing magnified view of the machined, inner diameter surface of Bushing 4, at 1000X.

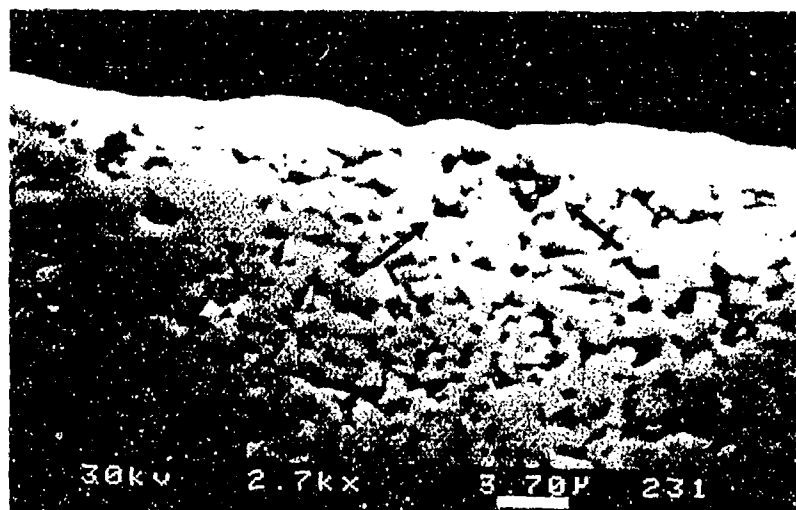


Figure 39. SEM micrograph showing a cross-sectional area of the inner diameter of Bushing 3, at 2700X. Arrows point to slight degradation caused by the wire EDM process.

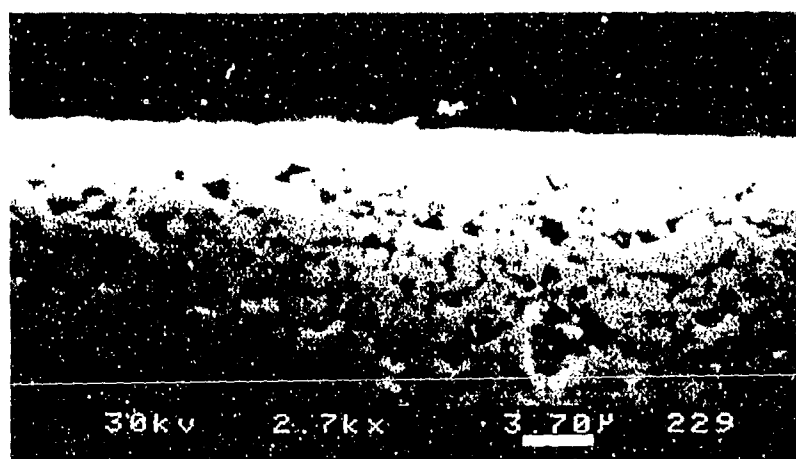


Figure 40. SEM micrograph showing a cross-sectional area of the inner diameter of Bushing 4, at 2700X.

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